

Historical air quality database in Navarre, Spain (2011–2025): Harmonized hourly records and relational Star Schema of atmospheric pollutants

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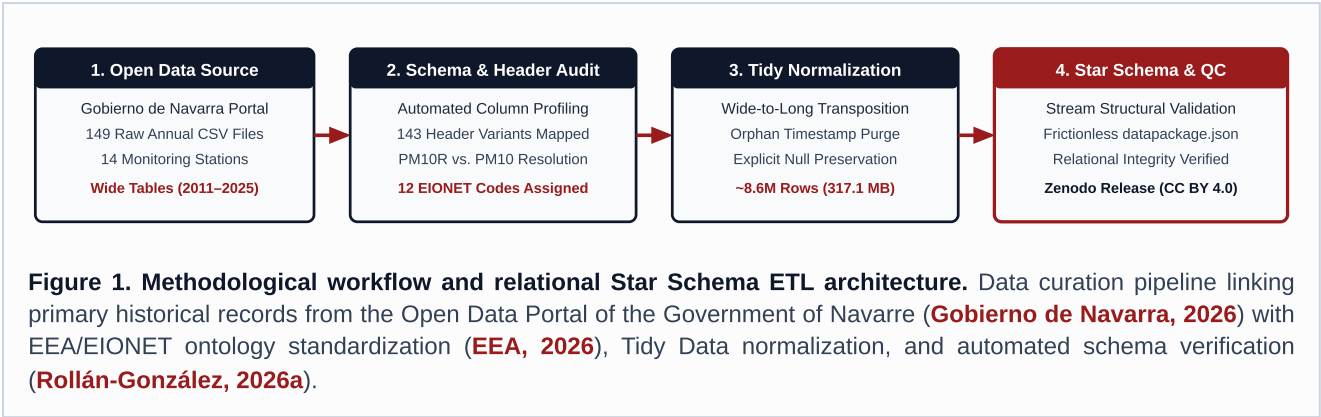
ABSTRACT

Long-term, standardized baselines of atmospheric pollutants are essential for epidemiological modeling, boundary-layer chemistry research, and environmental policy evaluation. Although public administrations routinely monitor ambient air quality, multi-decadal records are frequently distributed across fragmented annual files with heterogeneous table structures and inconsistent naming conventions. Here we present a continuous, harmonized 15-year hourly dataset (2011–2025) of atmospheric pollutants in the Chartered Community of Navarre, Spain ([Rollán-González, 2026a](#)). Derived entirely from primary open data published by the Government of Navarre ([Gobierno de Navarra, 2026](#)), the dataset consolidates approximately 8.6 million hourly observations collected across $N = 14$ official monitoring stations and $N = 12$ chemical parameters. Using a deterministic Python ETL pipeline ([Rollán-González, 2026b](#)), 149 dispersed wide-format CSV files containing 143 column-header variations were normalized into a relational Star Schema compliant with Tidy Data principles ([Wickham, 2014](#)) and European Environment Agency (EEA / EIONET) numerical identifiers ([EEA, 2026](#)).

1. BACKGROUND & SUMMARY

Regional air quality monitoring networks generate high-resolution longitudinal archives that are indispensable for quantifying human exposure to particulate matter and reactive trace gases. In northern Spain, the Air Quality Surveillance Network of the Government of Navarre (*Red de Vigilancia de la Calidad del Aire de Navarra*, [Gobierno de Navarra, 2026](#); [MITECO, 2024](#)) operates automated fixed stations spanning urban background and traffic sites in the Pamplona Basin, industrial valleys in Alsasua and Lesaka, agricultural corridors along the Ebro Valley, and rural reference locations. Despite the high analytical quality of the official instrumentation, direct computational reuse of the historical archive over a 15-year window is hindered by structural heterogeneity common to administrative open-data portals: dispersion across 149 separate annual CSV files, unstandardized Spanish column labels (143 distinct header strings), decimal-comma formatting, and occasional coexistence of raw versus gravimetrically validated particulate matter series.

This Data Descriptor documents a derivative data-curation initiative focused exclusively on harmonizing, validating, and restructuring these pre-existing public records into a FAIR-compliant (Wilkinson et al., 2016), relational research database (Rollán-González, 2026a). Full institutional credit and primary authorship for physical air sampling, analyzer maintenance, and regulatory calibration belong exclusively to the Department of Rural Development and Environment of the Government of Navarre (Gobierno de Navarra, 2026). By decoupling geographical station attributes and chemical parameter metadata into dedicated dimension tables and enforcing strict temporal and null-value integrity, the resulting Star Schema substantially reduces storage overhead while enabling direct queries in SQL, Python, R, and Geographic Information Systems (GIS).

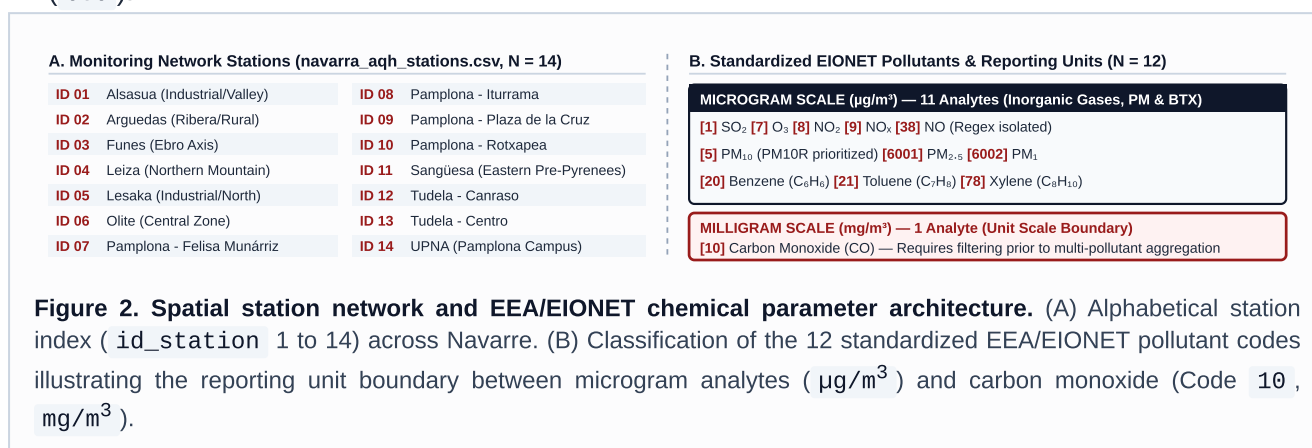


2. METHODS: DATA HARMONIZATION & CHEMICAL CURATION

Data acquisition, auditing, and relational transformation were executed in June 2026 using an automated, memory-efficient Python 3 pipeline (Rollán-González, 2026b). Five deterministic standardization rules were established to guarantee chemical accuracy and structural interoperability:

- 1. Pre-ETL header auditing and station indexing (audit_headers_navarra_aqh_2011_2025.py):** All 149 historical CSV files retrieved from the Government of Navarre portal (Gobierno de Navarra, 2026) were grouped by monitoring site and assigned sequential integer station keys (id_station 1 to 14 in alphabetical order: Alsasua to UPNA). By scanning file headers prior to full ingestion, the audit cataloged 143 distinct column-naming variants resulting from historical changes in calibration suffixes, unit annotations, and character spacing across the 2011–2025 period.
- 2. Resolution of the PM10 versus PM10R validation conflict:** Header profiling revealed that during specific historical reporting cycles, raw beta-attenuation particulate matter readings (PM10) and gravimetric-equivalence validated series (PM10R) were exported simultaneously within the same annual file. Whenever both columns coexist in a raw table, the ETL pipeline programmatically discards the unvalidated PM10 series and maps PM10R as the canonical PM10 parameter, ensuring that only officially corrected concentrations are retained.

3. **EEA / EIONET ontology standardization and substring disambiguation:** Local Spanish variable names were mapped to their official numerical identifiers in the European Environment Agency vocabulary (EEA, 2026): 1 (SO₂), 5 (PM₁₀), 7 (O₃), 8 (NO₂), 9 (NO_x), 10 (CO), 20 (Benzene, C₆H₆), 21 (Toluene, C₇H₈), 38 (NO), 78 (Xylene, C₈H₁₀), 6001 (PM_{2.5}), and 6002 (PM₁). To prevent substring collisions during automated parsing, rule evaluation follows a strict hierarchy: nitrogen monoxide (NO, Code 38) is evaluated last using regular-expression word boundaries (`\bNO\b`) to avoid false matches with NO₂ or NO_x, while `\bPM1\b` isolates sub-micron particulate matter from PM₁₀.
4. **Wide-to-Long relational normalization (`etl_navarra_aqh_2011_2025.py`):** Decimal commas in the raw files were standardized to floating-point dots and coerced to numeric types. Each wide multivariable table was transposed via `DataFrame.melt()` into a normalized long structure (Wickham, 2014). Records were processed station by station, sorted chronologically by `timestamp` and `pollutant`, assigned a global sequential primary key (`id`), and exported incrementally to the master fact table (`navarra_aqh_2011_2025_facts.csv`).
5. **Strict temporal integrity versus non-suppression of instrumental downtime:** Timestamps were standardized to ISO 8601 format (`YYYY-MM-DD HH:MM:SS`) reflecting local capture time (CET/CEST). Trailing lines or corrupted records lacking a valid timestamp were purged via `dropna(subset=['timestamp'])`. Conversely, whenever a valid timestamp was recorded but the analyzer was undergoing calibration, maintenance, or power outage, the row was preserved with an explicit empty value (`""`), mathematically distinguishing sensor downtime from zero atmospheric concentration (`0.0`).



Repository Architecture & Open Access Files (Rollán-González, 2026a): Hosted on Zenodo under a CC BY 4.0 license (Version v1 DOI: [10.5281/zenodo.21270386](https://doi.org/10.5281/zenodo.21270386); Concept DOI: [10.5281/zenodo.21270385](https://doi.org/10.5281/zenodo.21270385); GitHub: [Aimarus22/etl-can](https://github.com/Aimarus22/etl-can)). The repository integrates the three relational CSV tables (`facts`, `stations`, and `pollutants`), the Python curation and quality-control scripts, machine-actionable schema descriptors (`datapackage.json` and `ai-manifest.jsonld`), and comprehensive methodological documentation (`README.md`).

3. DATA RECORDS & RELATIONAL VARIABLE CODEBOOK

The dataset replaces redundant wide text files with a normalized three-table Star Schema. In this relational architecture, the central fact table stores only numerical foreign keys and measurement values, linking 1:1 with the spatial and chemical master dimension tables. Table 1 defines the variable specifications for the core fact table and the spatial station dimension table:

Table & Column	Data Type	Description & Standard Format	Analytical Function & Usage Notes
1. CORE FACT TABLE: NAVARRA_AQH_2011_2025_FACTS.CSV (~8.6 MILLION ROWS 317.1 MB)			
id	Integer	Sequential unique row identifier (1 to ~8,600,000).	Primary key: Guarantees immutable record-level traceability across the 15-year series.
timestamp	Datetime	ISO 8601 string (YYYY-MM-DD HH:MM:SS) in local capture time (CET/CEST).	Temporal index: Represents integration of the preceding hour; retains official DST shifts.
id_station	Integer	Surrogate station identifier (1 to 14).	Spatial foreign key: Links 1:1 with navarra_aqh_stations.csv ; eliminates string redundancy.
pollutant	Integer	Official EEA / EIONET numerical pollutant code (1 to 6002).	Chemical foreign key: Links 1:1 with navarra_aqh_pollutants.csv ; determines unit scale.
value	Number (Float)	Measured concentration (≥ 0.0) or empty cell ("") for missing records.	Primary physical metric: Expressed in mg/m ³ for CO (Code 10) and µg/m ³ for all other analytes.
2. SPATIAL DIMENSION TABLE: NAVARRA_AQH_STATIONS.CSV (N = 14 MONITORING STATIONS 1.2 KB)			
id_station	Integer	Unique station primary key (1 = Alsasua to 14 = UPNA).	Primary key: Relational target for facts.id_station .
station_name	String	Official municipality or urban district name in UTF-8.	Geographical label: Identifies urban, industrial, and rural monitoring locations.
ine_code	String	5-digit Spanish National Statistics Institute code (Prefix 31 = Navarre).	Administrative join key: Links directly with official INE municipal and demographic GIS layers.
latitude	Number (Float)	Geographic latitude in decimal degrees (WGS84 ellipsoid).	Geospatial coordinate: Enables spatial plotting and dispersion modeling in GIS/R.
longitude	Number (Float)	Geographic longitude in decimal degrees (WGS84 ellipsoid).	Geospatial coordinate: Paired with latitude for exact station georeferencing.

Spatial decoupling and GIS interoperability: Replacing repetitive station names and coordinate strings across 8.6 million rows with the integer foreign key `id_station` reduces the uncompressed CSV footprint to 317.1 MB. Researchers performing spatial joins can link `navarra_aqh_stations.csv` directly to municipal boundary polygons via `ine_code` or project point locations using the WGS84 decimal coordinates (`latitude` , `longitude`).

Table 2 completes the relational codebook by specifying the structure of the chemical parameter dimension table (`navarra_aqh_pollutants.csv`), which maps each numerical EIONET key to its stoichiometric formula and regulatory reporting unit:

Table & Column	Data Type	Description & Standard Format	Analytical Function & Usage Notes
3. CHEMICAL DIMENSION TABLE: NAVARRA_AQH_POLLUTANTS.CSV (N = 12 EIONET ANALYTES 500 BYTES)			
<code>pollutant</code>	Integer	EEA / EIONET standard integer identifier (1, 5, 7, 8, 9, 10, 20, 21, 38, 78, 6001, 6002).	Primary key: Ensures pan-European semantic interoperability with AirBase / AQ e-Reporting.
<code>pollutant_name</code>	String	Official common name of the atmospheric pollutant in Spanish.	Human-readable label: Facilitates reporting and bilingual dictionary lookup.
<code>chemical_formula</code>	String	IUPAC / technical chemical notation (SO ₂ , PM ₁₀ , O ₃ , NO ₂ , NO _x , CO, C ₆ H ₆ , C ₇ H ₈ , NO, C ₈ H ₁₀ , PM _{2.5} , PM ₁).	Analytical symbol: Standard label for publication plots and chemical grouping.
<code>unit</code>	String	Regulatory reporting unit (µg/m ³ or mg/m ³).	Scale control attribute: Mandatory reference to prevent cross-unit aggregation errors.

Encoding of missing values and RFC 4180 compliance: Missing numerical observations in `value` are encoded strictly as empty cells (a trailing comma at the end of the line, `id,timestamp,id_station,pollutant,`) without text strings (such as `"NaN"`, `"NULL"`, or `"-999"`). All floating-point values use a period (`.`) as the decimal separator, ensuring seamless ingestion across SQL databases, Apache Parquet, Python/pandas, and R.

4. TECHNICAL VALIDATION & USAGE NOTES

- Automated structural quality control (`qc_navarra_aqh_2011_2025.py`) & Frictionless schema:** Following ETL compilation, the master fact table was audited using a line-by-line stream validation script that verifies column geometry and relational key completeness without memory saturation. Across all ~8.6 million records, the audit confirmed zero structural delimiter errors (strictly 5 columns per row) and 100% non-null integrity across `id`, `timestamp`, `id_station`, and `pollutant`. Machine-readable field constraints are formally specified in `datapackage.json` (Fowler, 2017).
- Mixed reporting scales across chemical parameters:** Because the fact table stores all analytes in a single normalized `value` column, users must always group or filter by `pollutant` before computing summary statistics. Carbon monoxide (Code `10`) is reported in milligrams per cubic meter (`mg/m3`), whereas the remaining 11 pollutants are reported in micrograms per cubic meter (`µg/m3`).
- Instrumental evolution and spatial representativeness bias:** Over the 15-year monitoring window (2011–2025), routine analyzer replacements may influence baseline detection limits between earlier (2011–2015) and later periods. Spatially, the 14 monitoring stations prioritize demographic and industrial areas (Pamplona Basin and Ebro corridor) over high-mountain Pyrenean valleys, and capture ambient point concentrations rather than individual mobile exposure trajectories.

5. DECLARATIONS, AUTHORSHIP & REPOSITORY INVENTORY

PRIMARY DATA ATTRIBUTION & COMPETING INTERESTS

Primary raw measurements originate entirely from the Open Data Portal of the Government of Navarre (*Departamento de Desarrollo Rural y Medio Ambiente / Red de Vigilancia de la Calidad del Aire*, **Gobierno de Navarra, 2026**), which holds full credit for physical monitoring. **Funding & Competing Interests:** This curation project was conducted autonomously and self-funded by the author without external grants. The author declares no competing financial or institutional interests.

DECLARATION OF GENERATIVE AI & CREDIT TAXONOMY

In compliance with international publishing standards (ICMJE/COPE), AI-assisted tools were used strictly for code formatting, schema structuring, and academic English translation and syntax editing. **No empirical data were generated, imputed, or hallucinated by AI.** **CRedit Roles:** A. Rollán-González: Conceptualization, Methodology, Software, Validation, Data Curation, Writing – Original Draft & Editing.

Repository Artifact (Zenodo v1)	Size / Format	MD5 Integrity Checksum	Functional Role
navarra_aqh_2011_2025_facts.csv	317.1 MB (CSV)	d93aafdaff39ba3885666d6c496c0ed7	Core Star Schema Fact Table
navarra_aqh_stations.csv pollutants.csv	1.2 kB 500 B	4d510991a7... 951c59ffb8...	Spatial (N=14) & EIONET (N=12) Dims
audit_headers*.py etl*.py qc*.py	15.3 kB (Python)	d311ba... 15d9ea... 3d1a1d...	Audit, Tidy ETL & Stream QC Scripts
datapackage.json ai-manifest.jsonld	5.1 kB 3.3 kB	4ce4ee6069... 725d0dec09...	Frictionless Schema & Metadata
README.md	15.9 kB (MD)	55b58aece900637adc43c8192d315bb6	Methodological Documentation

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